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Design requirements for ERD in diffusion-dominated media: how do injection interval, bioactive zones and reaction kinetics affect remediation performance?

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TITLE: Design requirements for ERD in diffusion-dominated media: how do injection interval, bioactive zones and reaction kinetics affect remediation performance?

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ABSTRACT BODY: Enhanced Reductive Dechlorination (ERD) has been successfully used in high permeability media, such as sand aquifers, and is considered to be a promising technology for low permeability settings. Pilot and full-scale applications of ERD at several sites in Denmark have shown that the main challenge is to get contact between the injected bacteria and electron donor and the contaminants trapped in the low-permeability matrix. Sampling of intact cores from the low-permeability matrix has shown that the bioactive zones (where degradation occurs) are limited in the matrix, due to the slow diffusion transport processes, and this affects the timeframes for the remediation. Due to the limited ERD applications and the complex transport and reactive processes occurring in low-permeability media, design guidelines are currently not available for ERD in such settings, and remediation performance assessments are limited. The objective of this study is to combine existing knowledge from several sites with numerical modeling to assess the effect of the injection interval, development of bioactive zones and reaction kinetics on the remediation efficiency for ERD in diffusion-dominated media.
A numerical model is developed to simulate ERD at a contaminated site, where the source area (mainly TCE) is located in a clayey till with fractures and interbedded sand lenses. Such contaminated sites are common in North America and Europe. Hydro-geological characterization provided information on geological heterogeneities and hydraulic parameters, which are relevant for clay till sites in general. The numerical model couples flow and transport in the fracture network and low-permeability matrix. Sequential degradation of TCE to ethene is modeled using Monod kinetics, and the kinetic parameters are obtained from laboratory experiments. The influence of the reaction kinetics on remediation efficiency is assessed by varying the biomass concentration of the specific degraders. The injected reactants (donor and bacteria) are assumed to spread in horizontal injection zones of various widths, depending on the development of bioactive zones. These injection zones are spaced at various intervals over depth, corresponding to the injection interval chosen.
The results from the numerical model show that remediation timeframes can be reduced significantly by using closely spaced injection intervals and by ensuring the efficient spreading of the reactants into the clay till matrix. In contrast the reaction kinetics affect mass removal only up to a point where diffusive transport becomes limiting. Based on these results, guidelines on when ERD can be an effective remediation strategy in practice are provided. These take the form of dimensionless groupings (such as the Damkohler number), which combine site specific (physical and biogeochemical) and design parameters, and graphs showing how the main parameters affect remediation timeframes. Finally it is shown how model results can be used as input to other decision making tools such as life cycle

assessment to guide remedial choices.

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